

Appendix A

Changes in Highway Investment Requirements Methodology

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Changes in Highway Investment Requirements Methodology

Investment requirements for highway preservation and highway and bridge capacity expansion are modeled by the Highway Economic Requirements System (HERS), which was introduced in the 1995 C&P report. This appendix describes the basic HERS methodology and approach in slightly more detail than is presented in Part II, including the treatment of high cost improvements, the allocation of investment across improvement types, and the calculation of the highway backlog. It also explores some of the improvements that have been made to the model since the 2002 C&P report, including changes in the pavement deterioration equations, improvement costs matrix, capacity calculations, delay equations, and the evaluation of widening options. The HERS model has been modified to import section-specific data concerning current and future operations strategies and ITS deployments, as well as freight forecasts; this appendix provides a summary of how these data were developed and utilized in the HERS analysis.

Highway Economic Requirements System

The HERS model initiates the investment requirement analysis by evaluating the current state of the highway system using information on pavements, geometry, traffic volumes, vehicle mix, and other characteristics from the Highway Performance Monitoring System (HPMS) sample dataset. Using section-specific traffic growth projections, HERS forecasts future conditions and performance across several funding periods. As used in this report, the future analysis covers four consecutive 5-year periods. At the end of each period, the model checks for deficiencies in eight highway section characteristics: pavement condition, surface type, volume/service flow (V/SF) ratio, lane width, right shoulder width, shoulder type, horizontal alignment (curves), and vertical alignment (grades).

Once HERS determines a section's pavement or capacity is deficient, it will identify potential improvements to correct some or all of the section's deficient characteristics. The HERS model evaluates seven kinds of improvements: reconstruction with more lanes, reconstruction to wider lanes, pavement reconstruction, major widening, minor widening, resurfacing with shoulder improvements, and resurfacing. For each of these seven kinds of improvements, HERS evaluates four alignment alternatives: improved curves and grades, improved curves only, improved grades only, or no change. Thus, HERS has 28 distinct types of improvements to choose from. When analyzing a particular section, HERS actively considers no more than six alternative improvement types at a time: one or two aggressive improvements that would address all of the section's deficiencies and three or four less-aggressive improvements that would address only some of the section's deficiencies.

When evaluating which potential improvement, if any, should be implemented on a particular highway section, HERS employs incremental benefit/cost analysis. The HERS model defines benefits as reductions in direct highway user costs, agency costs, and societal costs. Highway user benefits are defined as reductions in travel time costs, crash costs, and vehicle operating costs. Agency benefits include reduced maintenance costs and the residual (salvage) value of the projects. Societal benefits include reduced vehicle emissions. Increases in any of these costs resulting from a highway improvement (such as higher emissions rates at high speeds) would be factored into the analysis as a "disbenefit."

Q. Where can I find more detailed technical information concerning the HERS model?

A. The FHWA periodically develops a Highway Economic Requirements System: Technical Report. The most recent printed edition is dated December 2000 and is based on HERS version 3.26, which was utilized in the development of the 1999 edition of the C&P Report.

The FHWA also has developed a modified version of HERS for use by states. This model, HERS-ST, builds on the primary HERS analytical engine, but adds in a number of customized features to facilitate analysis on a section-by-section basis. HERS-ST version 2.0 is based on HERS version 3.54, which was utilized in developing the 2002 edition of the C&P Report. The Highway Economic Requirements System—State Version: Technical Report is available at <http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersdoc.htm>.

The HERS-ST model will be updated to take advantage of the upgrade analytical procedures described later in this appendix, which will be reflected in future editions of the Technical Report.

These benefits are divided by the costs of implementing the improvement to arrive at a benefit/cost ratio (BCR) that is used to rank potential projects on different sections. The HERS model implements improvements with the highest BCR first. Thus, as each additional project is implemented, the marginal BCR and the average BCR of all projects implemented decline. However, until the point where the marginal BCR falls below 1.0 (i.e., costs exceed benefits), total net benefits will continue to increase as additional projects are implemented. Investment beyond this point would not be economically justified, since it would result in a decline in total net benefits.

Because the HERS model analyzes each highway segment independently, rather than the entire transportation system, it cannot fully evaluate the network effects of individual highway improvements. This was one of the limitations of the model cited in a June 2000 report by the United States Government Accountability Office (GAO), *FHWA's Model for Estimating Highway*

Needs is Generally Reasonable, Despite Limitations. While efforts have been made to indirectly account for some network effects, HERS is fundamentally rooted to its primary data source, the national sample of independent highway sections contained in the HPMS. To fully recognize all network effects, it would be necessary to develop significant new data sources and analytical techniques.

Allocating HERS and NBIAS Results Among Improvement Types

Highway capital expenditures can be divided among three types of improvements: system preservation, system expansion, and system enhancements (see Chapters 6 and 7 for definitions and discussion). All improvements selected by HERS that did not add lanes to a facility were classified as system preservation. For improvements that added lanes, the total cost of the improvement was split between preservation and expansion, since widening projects typically improve the existing lanes of a facility to some degree. Also, adding new lanes to a facility tends to reduce the amount of traffic carried by each of the old lanes, which may extend their pavement life. The allocation of widening costs between preservation and capacity expansion was based on the improvement cost inputs and implementation procedures within the HERS model.

All investment requirements projected by the National Bridge Investment Analysis System (NBIAS) are classified as preservation only, since new bridge and bridge capacity expansion investments are implicitly modeled by HERS. The HERS model does not currently identify investment requirements for system enhancements.

Highway Investment Backlog

To calculate this value, HERS has been modified to evaluate the current state of each highway section before projecting the effects of future travel growth on congestion and pavement deterioration. Any potential improvement that would correct an existing pavement or capacity deficiency, and that has a BCR greater than or equal to 1.0, would be considered to be part of the current highway investment backlog.

As noted in Chapter 7, the backlog estimate produced by HERS does not include either rural minor collectors or rural and urban local roads and streets (since HPMS does not contain sample section data for these functional systems), nor does it contain any estimate for system enhancements.

Travel Demand Elasticity

The States furnish projected travel for each sample highway section in the HPMS dataset. As described in Chapters 7 and 9, HERS assumes that the HPMS forecasts are constant-price forecasts, meaning that the generalized price facing highway users in the forecast year is the same as in the base year. The HERS model uses these projections as an initial baseline, but alters them in response to changes in highway user costs on each section over time. The travel demand elasticity procedures in HERS recognize that as a highway becomes more congested, some potential travel on the facility may be deterred, and that when lanes are added to a facility, the volume of travel may increase.

Q. What are some examples of the types of behavior that the travel demand elasticity features in the HERS represent?

A. If highway congestion worsens in an area, this increases travel time costs, which might cause highway users to shift to mass transit or cause some people living in that area to forgo some personal trips they might ordinarily make. For example, they might be more likely to combine multiple errands into a single trip because the time spent in traffic on every trip discourages them from making a trip unless it is absolutely necessary.

In the longer term, people might make additional adjustments to their lifestyles in response to changes in user costs that would impact their travel demand. For example, if travel time in an area is reduced substantially for an extended period of time, some people may make different choices about where to purchase a home. If congestion is reduced, purchasing a home far out in the suburbs might become more attractive, since commuters would be able to travel farther in a shorter period of time.

The basic principal behind demand elasticity is that, as the price of a product increases relative to the price of other products or services, consumers will be inclined to consume less of it. Conversely, if the price of a product decreases, consumers will be inclined to consume more of it, either in place of some other product or in addition to their current overall consumption.

The travel demand elasticity procedures in HERS treat the cost of traveling a facility as its price. As a highway becomes more congested, the cost of traveling the facility (i.e., travel time cost) increases, which tends to constrain the volume of traffic growth. Conversely, when lanes are added and highway user costs decrease, the volume of travel tends to increase.

As a result of travel demand elasticity, the overall level of highway investment has an impact on projected travel growth. For any highway investment requirement scenario that results in a

decline in average highway user costs, the effective vehicle miles traveled (VMT) growth rate tends to be higher than the baseline rate. For scenarios in which highway user costs increase, the effective VMT growth rate tends to be lower than the baseline rate. This effect is discussed in more detail in Chapter 9.

Demand elasticity is measured as the percentage change in travel relative to the percentage change in costs faced by users of the facility. Thus, an elasticity value of -0.8 would mean that a 10 percent decrease in user costs would result in an 8 percent increase in travel.

HERS Pavement Model and Improvement Costs

Two of the key assumptions and internal calculations used by HERS are the rate of pavement deterioration and the unit cost (per lane-mile) of the various improvements recommended by HERS. Both of these have been updated since the previous C&P report.

Pavement Deterioration Model

Versions of HERS (and its predecessor models) used for previous editions of the C&P report incorporated an older pavement deterioration model based on the 1986 version of the American Association of State Highway and Transportation Officials (AASHTO) Pavement Design Guide. For this version, the deterioration models for both flexible and rigid pavement have been updated to reflect the 1993 version of the AASHTO Guide. The new models use the same basic format as the old ones (based on equivalent single-axle loads), but include additional design parameters, such as reliability factors. Forecast pavement deterioration rates under the new models are somewhat lower than with the old model, reflecting the improved design standards, materials, and construction methods that are being applied to modern pavements. Additional research efforts are currently underway that should result in more significant refinements to the pavement modeling in HERS that should be available for the 2008 edition of the C&P report (see Part V).

Improvement Costs

The FHWA has updated both the values used for unit improvement costs and the way in which they are applied. The new improvement cost values were calculated based on highway project data from six states (Oregon, Nebraska, Oklahoma, Indiana, Ohio, and Vermont) that each use AASHTO's Transport system for tracking project costs. The data were then analyzed to derive the cost of typical improvements of different types on different classes of roadways. For rural areas, separate values were calculated by terrain and functional class, consistent with past versions of the cost table. For urban areas, the table format was altered slightly; cost values were now broken down by functional class and by urbanized area size, whereas they had previously been broken down by roadway type (a different field in the HPMS).

The application of the estimated improvement costs to different types of improvements also has been changed. The costs of improvements to existing lanes and the costs of adding lanes are now calculated separately (but aggregated for an improvement including both), making the values in the cost table more intuitive and consistently applied. Realignment costs are now calculated using the same table format described above, rather than using a separate procedure as previously.

For those sections coded in the HPMS as having limited widening feasibility, the costs of adding capacity have been significantly increased to more accurately reflect actual costs of recent projects that have been undertaken in these types of situations. In rural areas, the costs of "high cost lanes" have been set based on the estimated cost of constructing parallel routes; in mountainous areas, this is assumed to involve significant blasting. In densely populated urbanized areas, double-decking or tunneling may be the only potential options for adding highway capacity in this type of situation, and the cost matrix has been adjusted to reflect this. Realignment improvements on sections coded as having limited widening feasibility are also considered

to be made at a higher cost, similar to the approach used for lane additions. For sections coded in the HPMS as having unlimited widening feasibility (i.e., three or more lanes), the HERS allows only a certain number of lanes to be added at “normal cost” (which varies depending on the functional class) and applies the high cost lane factors to further widening beyond that point.

Further research is underway in this area that is expected to produce more refined estimates of the per-lane-mile costs for high-cost transportation capacity investments (see Part V).

HERS Capacity and Delay Analysis

Several modifications have been made to the capacity and delay calculations used by HERS. These include the estimates of highway capacity based on section data, the calculation of work zone delay, procedures used to determine the number of lanes to be added, and limitations on the number of lanes that may be added at normal cost.

Highway Capacity Calculations

The procedures used in the HPMS Submittal software to calculate highway capacity were revised in the 2001 data year, consistent with the *2000 Highway Capacity Manual*. As these calculations apply to the data used in HERS, the capacity calculations used in HERS have been revised to match those used in the HPMS source dataset.

Work Zone Delay

A typical feature of highway projects is that restrictions must be placed on existing travel lanes during at least part of the time that the work is going on (even in cases where lanes are being added). These restrictions can result in significant, temporary losses of effective highway capacity, resulting in additional traveler delay during the time period that the work zone is in place. This work zone delay can represent a significant disbenefit to highway users for some types of improvements. The HERS model has now been modified to include work zone delay in its benefit calculations.

To implement this new procedure in HERS, State departments of transportation were consulted about the duration of and roadway constrictions typically associated with the types of improvements modeled by HERS. The reduced capacity of the roadway is calculated as a function of both reduced capacity per lane and a reduced number of travel lanes. For some types of improvements (such as simple resurfacing on congested freeways and arterials), it was assumed that the capacity restrictions are applied only during off-peak periods. The reduced capacity levels were then used in conjunction with existing travel volumes to calculate the additional travel delay caused by the work zone.

Incremental Lane Additions

When considering adding lanes to correct a capacity deficiency, HERS calculates the number of lanes that would be needed to accommodate traffic volumes in the future design year (typically 20 years hence). In prior versions, HERS has only considered improvements with this Design Number of Lanes (DNL) when evaluating potential capacity improvements. The model now considers a broader array of potential lane addition improvements, including $\frac{1}{2}$ DNL, $\frac{3}{4}$ DNL, and DNL+2. For example, if HERS computes a DNL of four lanes, it will now evaluate the effects of adding zero, two, four, or six (the $\frac{3}{4}$ DNL option would not be invoked; the HERS model typically builds to an even number of lanes).

In some cases, this results in an intermediate widening option (i.e., add two lanes) being chosen where a larger, more costly option either might have been implemented (i.e., add four lanes) or rejected in favor of no lane addition at all. In general, by giving the model more options to choose from, the investment cost of achieving a given level of performance is reduced.

HERS Operations and Freight Analysis

For this report, HERS has been modified to accept section-specific data inputs from outside the HPMS sample dataset for the first time, which can be applied on an “optional” basis. These additional data inputs fall into two categories: current and future operations strategies and ITS deployments, and freight forecasts.

Operations Strategies and Improvements

For the first time, HERS has been modified to consider the impact of highway operations strategies and ITS deployments on highway system performance. For this initial effort, current and future investments in operations were modeled outside of HERS, but the impacts of these deployments were allowed to affect the internal calculations made by the model, thus also affecting the capital improvements considered and implemented in HERS. As discussed in Part V, a longer-term goal is to analyze operations as alternative investment strategies directly in HERS.

While numerous operations strategies are available to highway authorities (see Chapter 12), a limited number are now considered in HERS (based on the availability of suitable data and empirical impact relationships). The types of strategies analyzed can be grouped into three categories: arterial management, freeway management, and incident management as follows:

- Arterial Management
 - Signal Control
 - Electronic Roadway Monitoring
 - Variable Message Signs (VMS)
- Freeway Management
 - Ramp Metering (preset and traffic actuated)
 - Electronic Roadway Monitoring
 - VMS
- Incident Management
 - Incident Detection (free cell phone call number and detection algorithms)
 - Incident Verification (surveillance cameras)
 - Incident Response (on-call service patrols).

Creating the operations improvements input files for use in HERS involved four steps: determine current operations deployment, determine future operations deployments, determine the cost of future operations investments, and determine impacts of operations deployments.

Current Operations Deployments

To determine current operations deployments on the HPMS sample segments, data were used from three sources: HPMS universe data, HPMS sample data, and the ITS Deployment Tracking System. The data assignments that were made reflected the fact that operations deployments occur over corridors (or even over entire urban areas, as with traffic management centers).

Future Operations Deployments

For future ITS and operations deployments, two scenarios were developed. For the “Continuation of Existing Deployment Trends” scenario, an examination of current congestion levels compared with existing deployments was made to set the congestion level by urban area size for each type of deployment. For the “Aggressive Deployment” scenario, an accelerated pace of deployment above existing trends was assumed.

Operations Investment Costs

The unit costs for each deployment item were taken from USDOT’s *ITS Benefits Database and Unit Costs Database* and supplemented with costs based on the Intelligent Transportation Infrastructure Deployment Analysis System (IDAS) model. Costs were broken down into initial capital costs and annual operating and maintenance (O&M) costs. Also, costs were determined for building the basic infrastructure to support the equipment, as well as for the incremental costs per piece of equipment that is deployed.

Impacts of Operations Deployments

Exhibit A-1 shows the estimated impacts of the different operations strategies considered in HERS. These effects include the following:

- Incident Management: Incident duration is reduced as well as the number of crash fatalities.
- Signal Control: The effects of the different levels of signal control are directly considered in the HERS delay equations.
- Ramp Meters and VMS: Delay adjustments are applied to the basic delay equations in HERS.

Based on the current and future deployments and the impact relationships, an operations improvements input file was created for each of the two deployment scenarios. The file contains section identifiers, plus current and future values (for each of the four funding periods in HERS) for the following five fields:

- Incident Duration Factor
- Delay Reduction Factor
- Fatality Reduction Factor
- Signal Type Override
- Ramp Metering.

Exhibit A-1 *Impacts of Operations Strategies*

Operations Strategy	Impact Category	Impact
Arterial Management		
Signal Control	Congestion/Delay	Signal Density Factor = $n(nx+2)/(n+2)$ where n = # of signals per mile x = 1 for fixed time control 2/3 for traffic actuated control 1/3 for closed loop control 0 for real-time adaptive control/SCOOT/SCATS Signal Density Factor is used to compute zero-volume delay due to traffic signals
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for corridor signal control (2 highest levels)
EM Vehicle Signal Preemption		
VMS	Congestion/Delay	-0.5% incident delay
Freeway Management		
Ramp Metering		
Preset	Congestion/Delay	New delay = 0.16 hrs per 1000 VMT – 0.13(original delay)
Traffic Actuated	Congestion/Delay Safety	New delay = 0.16 hrs per 1000 VMT – 0.13(original delay) -3% number of injuries and PDO accidents
Electronic Roadway Monitoring	Congestion/Delay	Supporting deployment for ramp metering and Traveler Info
VMS	Congestion/Delay	-0.5% incident delay
Incident Management		
Detection Algorithm/ Free Cell	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
Surveillance Cameras	Incident Characteristics Safety	-4.5% incident duration -5% fatalities
On-Call Service Patrols	Incident Characteristics Safety	-25% incident duration -10% fatalities
All Combined	Incident Characteristics Safety	Multiplicative reduction -10% fatalities

Freight Forecasts

In the sensitivity analyses in Chapter 10 of both this and the 2002 editions of the report, the HERS model's capability to adjust truck volume shares over time was utilized to test the sensitivity of the results to differential rates of future travel growth between trucks and passenger vehicles, based on national-level forecasts. This capability could be applied only on a functional class basis, however (meaning that all sections in a given functional class would have the same truck growth factor).

For this report, HERS has been modified to accept section-specific truck growth forecasts where available. The procedure also allows for alternative base year truck volume levels for individual sections to be substituted for the HPMS values if more detailed data are available (such as from automated truck counters installed on many roads in the United States).

The section-specific truck forecast and volume data used in the Chapter 10 analysis were derived from the FHWA's Freight Analysis Framework (FAF) (see Chapter 13). The FAF data (which use a 1998 base year and include a forecast for 2020) were matched to the 2002 HPMS sample data sections used in HERS in this report where possible. In all, it was possible to match the FAF data to approximately 33,000 of the 111,000 sections in the 2002 HPMS data. For sections that could not be matched, the truck growth factors for each functional class described above were applied.